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Exploring Higher-Order Effects of Vehicle Mobility Model Fidelity in M&S

73rd Military Operation Research Society Symposium
22 June 2005
West Point, NY

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Outline

- Problem
- Objective & Scope
- Selected Previous Related Work
- Terms and Definitions
- Approach
- Critical Issues
- Vignettes
- Simulations
- Emerging Results
- Future Work
- Summary

Problem

- It has been shown that fidelity of mobility models makes a difference in measures of ground vehicle performance (e.g., time to reach objective)
- Does this difference then result in higher-order effects which impact measures of outcome and effectiveness?
- Moreover, does this result in different conclusions concerning essential elements of analysis for programs (e.g., FCS)?

Objective & Scope

- Objective:
  - Conduct an initial investigation into whether there are significant higher-order effects that propagate through a simulation and impact resulting analysis
  - Outline future work issues and plan
- Scope:
  - Ground vehicle mobility fidelity
  - Entity-level M&S
  - Limited scenarios
  - Eye on Future Force analysis

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Selected Previous Related Work

- Goerger, S., Goerger, N., and Durda, D., *Assessing Effects of Enhanced Fidelity for Ground Vehicle Mobility in Combat Models*, 71st MORSS presentation, June 2003
- West P.D., Farr J.V., Fortier G.S., Lilly K.D., Ingalls G.D. *The effect of cold weather on tactical operations*, United States Military Academy, West Point, NY, Technical Report No. FY97/1, 1997
- Wolf, E.S., Sanchez, S., Goerger, N., and Brown, L. "Using Agents to Model Logistics," under revision for *Military Operations Research*
- Lindquist, Joseph M., *An Analysis of Degraded Communications in the Army's Future Force*, M.S. Thesis, Naval Postgraduate School, Monterey, CA, June 2004
- Davis, P., and Bigelow, J., *Experiments in Multiresolution Modeling (MRM)*, RAND, MR-1004-DARPA, 1998
- Cioppa, Thomas M., *Efficient Nearly Orthogonal and Space-Filling Experimental Designs for High-Dimensional Complex Models*, Ph.D. Dissertation, Naval Postgraduate School, Monterey, CA, September 2002

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Terms and Definitions (for purposes of this briefing)

- **Fidelity:**
  - **"the degree to which a model or simulation reproduces the state and behavior of a real-world object or the perception of a real-world object, feature, condition, or chosen standard in a measurable or perceivable manner; a measure of the realism of a model or simulation; faithfulness"**
    Harmon, S.Y. (Ed.). (16 December 1998). *Fidelity ISG Glossary*. Ver 3.0. Simulation Interoperability Standards Organization (SISO), Fidelity Implementation Study Group (ISG), http://www.sisostds.org/doclib/doclib.cfm?SISO_RID_1000789
- **Resolution**:
  - **"the degree of detail used to represent aspects of the real world or a specified standard or referent by a model or simulation"**
    Department of Defense Modeling and Simulation Office (DMSO) (15 October 2001). *Verification, Validation and Accreditation Glossary*. https://www.dmso.mil/public/library/projects/ vva/glossary.pdf
- **Model:**
  - **"a physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process"**
    https://www.dmso.mil/public/library/projects/ vva/glossary.pdf
- **Simulation:**
  - **"a method for implementing a model over time"**
    https://www.dmso.mil/public/resources/glossary/results?do=get&def=457
- **Mobility includes:**
  - **Trafficability: speed which a ground vehicle can achieve**
  - **Movement (e.g., tactical troop movement)**

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Approach

- Frame the study in terms of relevant issues
  - Review Future Force and previous studies and analysis efforts (e.g., FCS, FFW)
  - Consider current operations and issues (e.g., Iraq)
  - Identify Essential Elements of Analysis (EEA)/sub EEA related to higher-order effects of mobility
- Develop measures of effectiveness (MOE) and measures of performance (MOP)
- Design and develop vignettes for initial investigation
- Employ family-of-simulations approach to garner insights
  - Utilize agent based model to identify significant factors and regions of interest pertaining to EEA (conduct large-scale experimental design)
  - Develop streamlined simulation with ProModel for experimentation
- Conduct exploratory analysis to identify factors and regions of interest related to MOE in MANA and ProModel

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Approach, Cont.

- Set up Large-Scale Experimental Designs for data farming in MANA *(future work)*
- Conduct statistical analysis *(future work)*
- Conduct sensitivity analysis with ProModel *(in progress)*
- Utilize findings to focus JCATS experimentation *(future work)*
- Outline future work issues and recommended path forward for follow-on development

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Framing the Study: Example Relevant Issues

EEA	Objective	MOE
What mix of sensors will provide increased situational understanding over the full-spectrum of operations?	Provide early situational/environmental information for convoy mission planning	Detection/identification of potential threats
Will system x improve mission effectiveness?	Ensure convoy operations provide required support assets	# of vehicles damaged/destroyed
Will system x improve mission efficiency for convoy operations?	Convoy operations adhere to mission standards	Total time convoy closed on destination
		Difference in NET/NLT closing time vs. actual closing time
		# of civilians killed (collateral damage)
What convoy TTPs will result in asymmetric threat reduction?	Reduce threats or attacks to convoy	% of convoy exposed to asymmetric threats
		# of attempted attacks on convoy
Will varying convoy TTPs reduce collateral damage in urban environments?		# of civilians killed (collateral damage)
Will network enabled operations improve the ability to simultaneously synchronize & use a combination of line of sight, beyond line of sight, & non-line of sight effects to more effectively & efficiently engage targets in all types of environments?		% of targets that receive desired effect

Mobility MOPs
Average vehicle speed
Maximum vehicle acceleration
Maximum vehicle braking
Target location error

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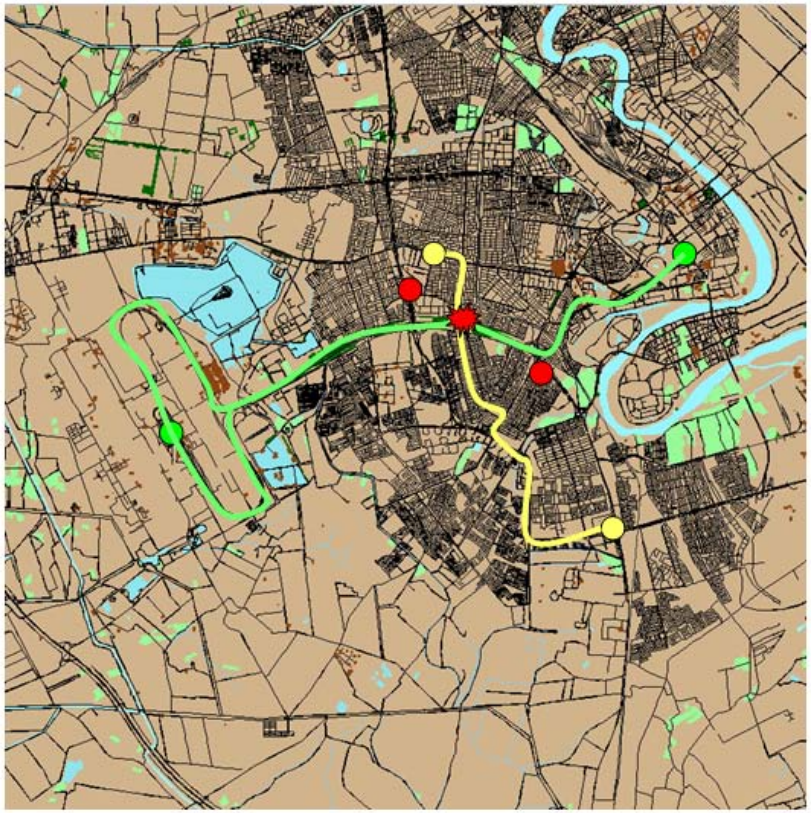
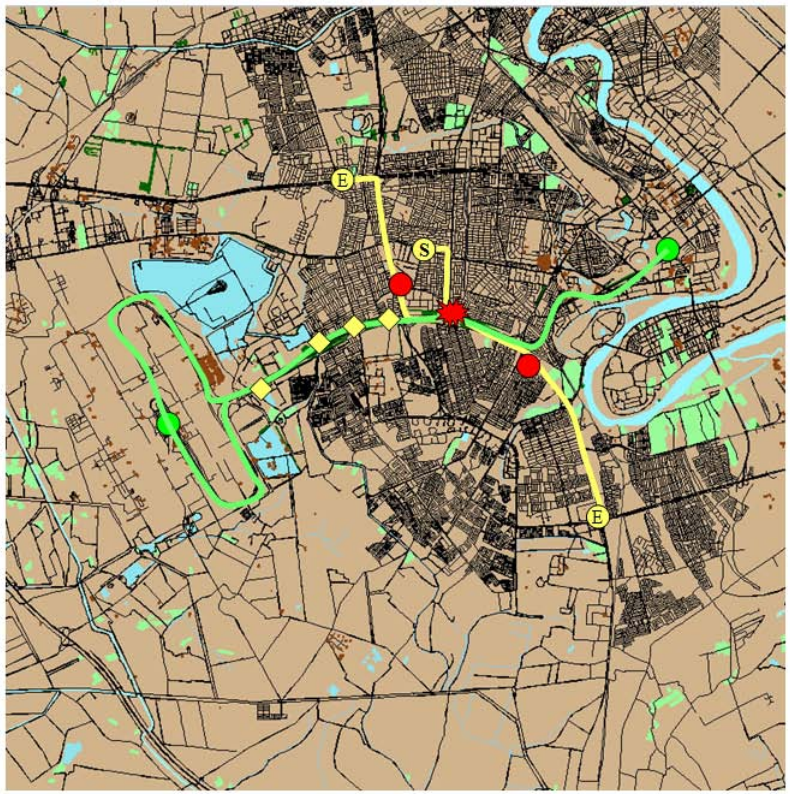
Vignette #1



- Convoy Start/End-Points
- Convoy Route (E <-> W)
- Engagement Area
- Bomber Truck Start/End Point
- Bomber Truck Route (Moving N->S)
  - Civilian Traffic moves east and west along the convoy route. Civilian traffic and pedestrians also move north and south across the convoy route in two or more areas to provide added congestion and confusion so the convoy cannot always maintain speed or identify the target vehicle as it approaches from the north.
- Spotters
  - Spotters notify bomb truck of approaching convoy so the truck can launch from its hid position in order to interdict the convoy at the EA.

Vignette #2



- Convoy Start/End-Points
- Convoy Route (E <-> W)
- Engagement Area
- Bomber Truck Start/End Point
- Bomber Truck Route (Moving N->S)
- Roving RPG Gunners
  - Civilian Traffic moves east and west along the convoy route. Civilian traffic and pedestrians also move north and south across the convoy route in two or more areas to provide added congestion and confusion so the convoy cannot always maintain speed or identify the target vehicle as it approaches from the north.
- Spotters
  - Spotters notify bomb truck of approaching convoy so the truck can launch from its hid position in order to interdict the convoy at the EA.

Simulations

- Map Aware Non-uniform Automata (MANA)
  - Agent-based model
  - Consists of entities representing military units
- ProModel
  - COTS
  - Constructive Simulation
  - Queue/Server
- Joint Conflict and Tactical Simulation (JCATS)
  - Combat Simulation
  - Entity Level
  - MOUT Operations

Sample MANA Factors

Properties	Squad Names	Blue (Default State)	Blue (Squad Shot At)	Blue (Injured)	Blue (Squad En Contact)
Next Waypoint		50	65	75	75
Alt Waypoint		0	15	0	0
Easy Going		54	0	54	25
Line Centre		0	0	0	0
Icon		4	4	4	4
Allegence		1	1	1	1
Threat		3	3	3	3
Movement Speed		29	29	25	29

- MANA uses slider scales to set properties or factors
- Some factors deal with distances or rates that agents move, sense, etc., in terms of cells per time step
- These factor settings should be selected considering “real world” rate and distance translations

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Synchronizing MANA Data to Real World Data (Rate and Distance)

- 1 time step = 1 sec
- 1 cell = 0.02306 km
- 43.365 cells = 1 km

477 cells (11 km)

1000 cells (23.06 km)

Speed Conversions

mph	kph	# of cells per sec
5	8	0.0964
10	16	0.1927
15	24	0.2891
20	32	0.3855
25	40	0.4818
30	48	0.5782
35	56	0.6746
40	64	0.7709
45	72	0.8673
50	80	0.9637
55	88	1.0600
60	97	1.1684
65	105	1.2648
70	113	1.3612
75	121	1.4576
80	129	1.5539
85	137	1.6503
90	145	1.7467
95	153	1.8430
100	161	1.9394

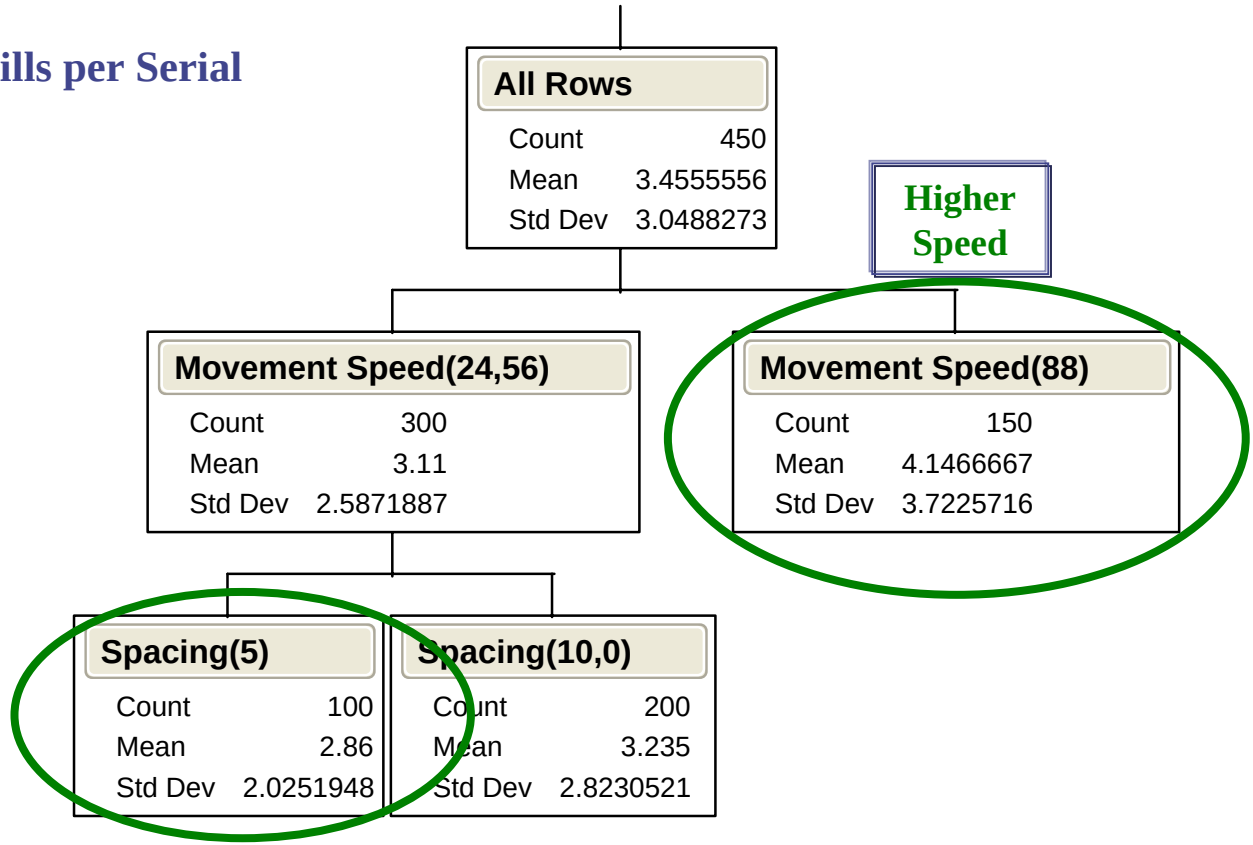
MANA Interface

- MANA development
- Have to set squad parameters
- Ran excursions to identify factors

Investigation of Convoy Casualties (Notional)

MOE: # Convoy Vehicle Kills per Serial

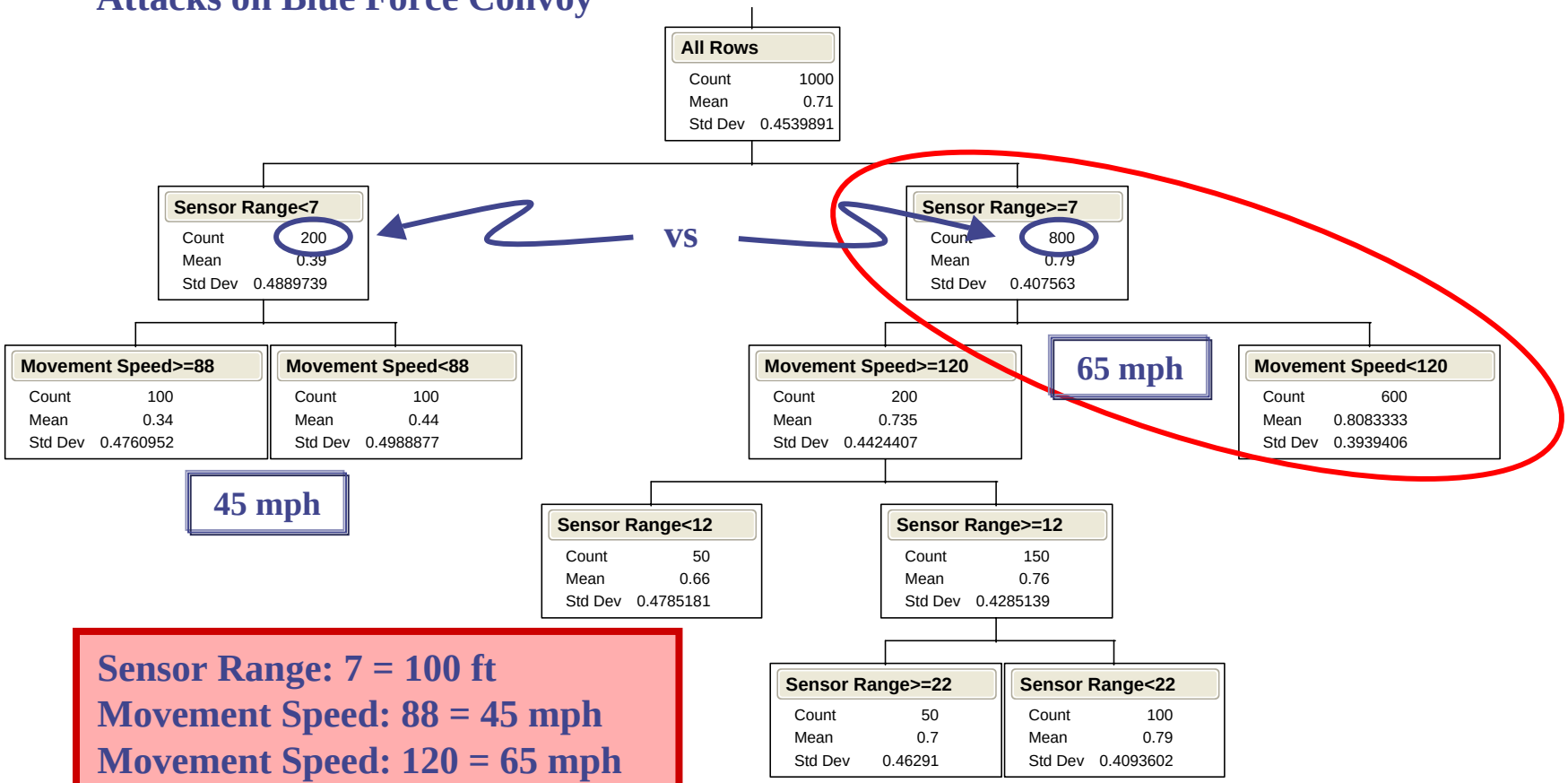
# Vehicle Kills	Count	Percent
0	376	83.56
1	2	0.44
2	12	2.67
3	28	6.22
4	21	4.67
5	11	2.44



Higher vehicle speeds are most critical for reducing casualties. At lower speeds, mid-level spacings are more effective than more closed or open spacings

Analysis of Movement Speed & Sensor Range on Successful Truck Attacks

MOE: # Successful Red Force Truck Attacks on Blue Force Convoy



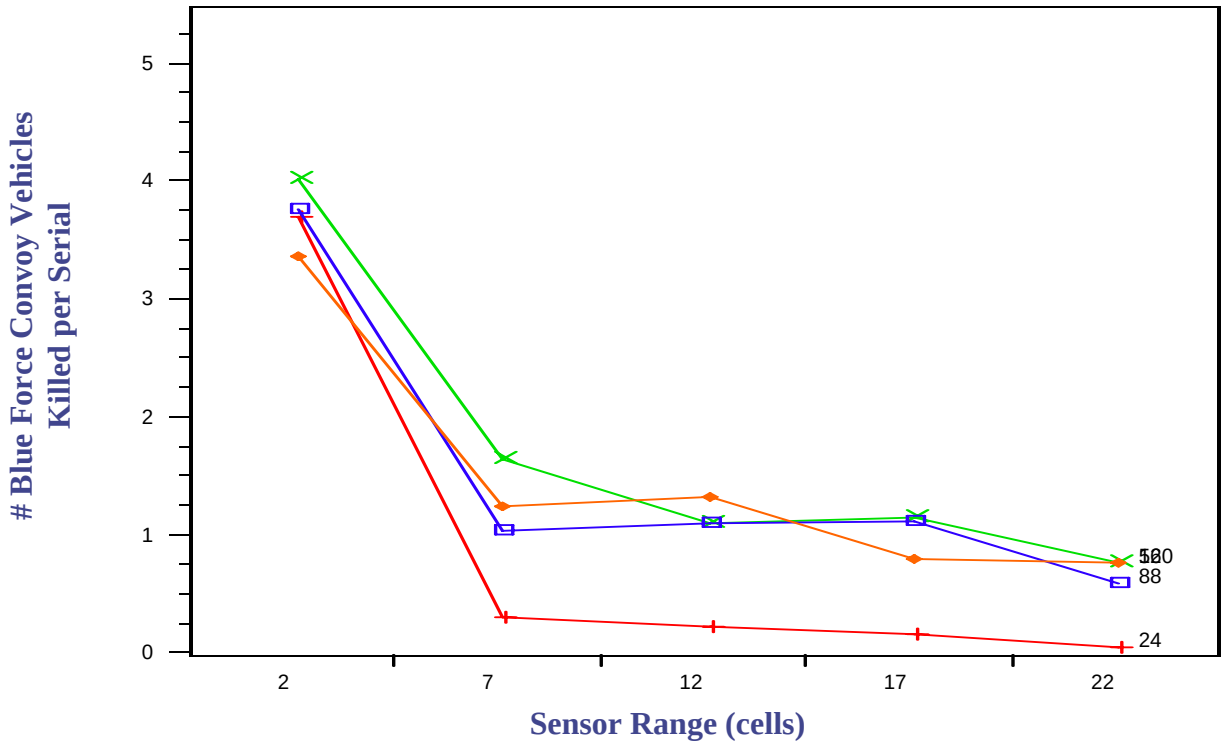
Sensor Range: 7 = 100 ft
Movement Speed: 88 = 45 mph
Movement Speed: 120 = 65 mph

Sensor Range >= 100 ft and Movement Speeds < 65 mph increase chance of the bomb truck intercepting the convoy; sensors override speed effects

Analysis of Movement Speed & Sensor Range Interactions

MOE: # Blue Force Convoy Vehicles Killed per Serial (per Run)

Interaction Plot for Sensor Range and Movement Rates



Interactions between speed and sensor rang, at speeds greater than 12 mph (24 cells), indicate speed does play a compounding role in number of Blue Force Convoy Vehicles Killed per Serial (per Run)

ProModel Interface

- Queue
  - Routes
- Server
  - Enemy Attacks

Future Work

- Set up Large-Scale Experimental Designs for data farming in MANA
- Conduct statistical analysis of data farming effort
- Finalize sensitivity analysis with ProModel
- Utilize findings from above to focus and conduct JCATS experimentation
- Outline issues and recommend path forward for follow-on development to create methodology for use of family of models to analyze higher order effects of mobility
- Study higher order effects of mobility model fidelity on system effectiveness of Quick Reaction Force employment
- Study higher order effects of mobility model fidelity on system effectiveness in restricted terrain (natural environments, off-road mobility)
- Study higher order effects of mobility model fidelity on system effectiveness in aggregate level models

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Summary

- Understanding the strength and limitations of simulation's ability to model mobility allows one to select the proper simulation to address the measures of effectiveness which answer the higher level essential elements of analysis. Increased mobility model fidelity is required in some simulations in order to enhance their ability to address higher order effects on systems.

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